# Reducing the Risk of Human Missions to Mars Through Testing


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# Background

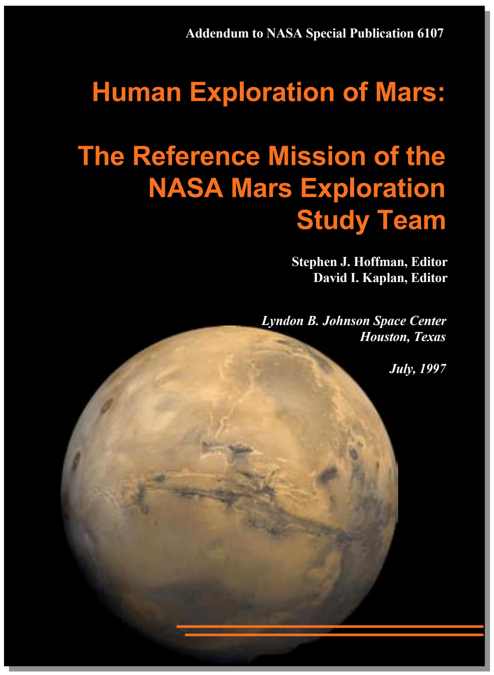
- **Purpose: Assess the potential benefits, in terms of risk reduction or mitigation, that could be gained by executing various Mars mission test bed options**
- **Test bed options include:**
  - Earth-based simulations and analogs,
  - Earth orbital missions, including accommodation on ISS, as well as missions in near-Earth space (robotic and/or human),
  - Lunar orbit and surface missions (robotic and/or human), and
  - Missions to Mars (robotic)
- **Study period of performance: July-November, 2003**
- **The intent was to develop a better understanding of the critical elements of future Mars mission concepts that should be tested prior to committing to the final mission**
- **As testing objectives are defined, they will be grouped into similar logical and achievable campaigns**
  - Similar to how Mercury and Gemini were critical steps in validating systems, techniques, and operational concepts needed for the Apollo missions

# Approach

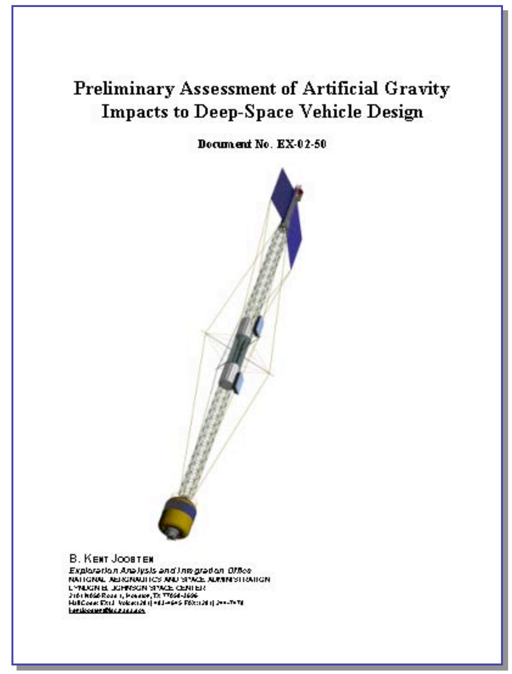
- Used  Mars Design Reference Mission (DRM), other  earlier work, as well as emerging mission concepts, such as the Nuclear-Electric Artificial-gravity study, as context for risk identification
- Reviewed information available from previous 1997 risk identification and assessment for relevance
- Polled system area experts to identify safety, technical, and programmatic risks
- Identified those risks that could be mitigated through testing
- For tests that could be performed on the moon,
  - Analyze list for tests for commonalities, synergies
  - Compare infrastructure required for tests with that required for lunar scientific investigations
  - Develop integrated (or, at least, concatenated) list of test objectives and lunar science objectives for integrated lunar architecture approach

# Mars Mission Context

- **Two distinctly different example Mars missions used as a basis for test team deliberations**




**Design Reference Mission 4 (1998)**
- Long-surface stay
- Zero-g Transits
- Solar-Electric/Aerobrake Propulsion




**NEP/Artificial-g Study (2002)**
- Short-surface stay
- Artificial-g Transits
- Nuclear-Electric Propulsion

# Example Critical Mars Mission Events

## EARTH VICINITY

- Operation of pre-deployed assets for long periods
- System Integration & Checkout
- Training, Planning & Simulation
- Cargo Launch – multiple, large mass, large volume
- Crew Launch – multiple possible
- Assembly & Checkout
  - Automated rendezvous & Docking
  - Deployment / Assembly
  - Fuel transfer
- Preparation for Departure – “All Systems Go”
- Crew Delivery / Earth Departure
- Vehicle Element Disposal – some options

## 2 TRANSIT TO MARS

- Deep-space hazard mitigation
- Trajectory Corrections, Deep-Space Maneuvers
- Vehicle Reconfiguration & Maintenance
- Arrival Preparation
- Mars Orbit Insertion or Aerocapture
- Rendezvous with Lander
- Lander Preparation
- Interplanetary Vehicle Safing
- Deorbit, Aero-Entry, and Precision Landing

## 3 SURFACE EXPLORATION

- Operations of pre-deployed assets for long-periods
- Hazard Avoidance, Terminal Descent
- Vehicle Safing, Power Deployment
- Routine EVAs
- Robust Exploration
- Vehicle Reconfiguration & Maintenance
- Preparation for Liftoff
- Ascent

## 4 TRANSIT FROM MARS

- Rendezvous and Docking
- Ascent Stage Disposal
- Preparation for Departure
- Mars Departure
- Deep-space hazard mitigation
- Trajectory Corrections, Deep-Space Maneuvers, Possible Venus Swing-by
- Vehicle Reconfiguration & Maintenance
- Arrival Preparation

## 5 EARTH RETURN

- Direct Entry, or Earth Orbit Insertion & Rendezvous with Earth Orbital Assets
- Interplanetary Vehicle Safing / Disposal
- Deorbit, Entry, and Landing
- Crew Retrieval

# Key Questions to Subject Matter Experts

1. **What are the critical elements (integrated systems, subsystems or components) that require testing in order to reduce potential Mars mission risks?**

2. **What are the benefits of testing each of the critical elements identified in #1 above at the following locations:**
    a. Earth-based simulations and analogs,
    b. Earth orbital missions (robotic and/or human), including accommodation on ISS,
    c. Missions in near-Earth space (robotic and/or human),
    d. Lunar orbit and surface missions (robotic and/or human), and
    e. Missions to Mars (robotic).

3. **For each applicable location, how would you propose the testing be conducted?**

4. **What is the rough scope of capabilities required to support each test objective at each applicable location described above?**

# Testing Venue Descriptions

- **Ground-Based Testing**

  Laboratory: Basic laboratory testing of system components in a breadboard or relevant environment. Includes computer simulation testing. Low to mid-TRL (1-6) technology testing.

  Integrated Physical Testing: Physical testing of integrated components in a relevant simulated environment. Includes testing of integrated systems and vehicles to validate the integrated performance of the “whole” . Low to mid-TRL (1-6) technology testing.

  Field: Tests conducted in remote locations on the Earth that provide similar environments expected on planetary surfaces. Low to mid-TRL (1-6) technology testing.

- **Low-Earth / Near-Earth Testing**

  ISS: Includes testing conducted at the ISS in LEO. Both IVA and EVA tests are included. Mid to high-TRL (6-9) technology testing.

  Near-Earth: Includes testing conducted in LEO, but not at ISS as well as testing conducted in Near-Earth space beyond LEO. Mid to high-TRL (6-9) technology testing.

- **Lunar Surface Testing**

  Robotic: Includes all testing conducted on unmanned lunar robotic missions. Generally considered small-scale missions with limited capabilities and resources. Mid to high-TRL (6-9) technology testing.

  Short-Stay: Includes short-stay human missions to the surface of the moon. Missions generally last several days (3-7), include modest capabilities (power, volume), and provide moderate exploration ranges (EVA and rover range). Mid to high-TRL (6-9) technology testing.

  Long-Stay: Includes longer stay human missions to the surface of the moon lasting months. Capabilities provided are significantly improved (power, volume) with the capability for repeated longer range field explorations. Mid to high-TRL (6-9) technology testing.

- **Mars Robotic**

  Small: Considered similar to today’s mission capability with constrained surface delivery capabilities and resources. Mid to high-TRL (6-9) technology testing.

  Large: Robotic missions much larger than those planned today with significantly greater capabilities. Missions which pre-deploy cargo for future human missions are included in this class. Mid to high-TRL (6-9) technology testing.

# An Example: EVA Systems

## Critical Elements to Test

- Space suit mobility & dexterity performance
- EVA communications / information systems
- Life support system component operation
- Space suit thermal protection & operation
- Dust protection and radiation protection
- EVA traverse mapping & route planning
- Surface mobility systems "trafficability"
- EVA system maintenance strategies

## Testing Venues & Benefits

- **Earth-based facilities**
  - Certification in ground-based simulators required before use
  - Both simulators and field tests allow "build a little; test a little" to provide greater insight to "go/no go" technical decisions
- **Near-Earth Flight Tests**
  - None identified
- **Lunar Tests**
  - Lunar surface tests can establish EVA systems functional performance capabilities in a similar environment
  - May prove useful for long-term "dry run" rehearsals and "what if" scenarios
- **Mars Robotic Missions**
  - Key to providing martian environmental and hazard data

## Testing Approach & Support Needed

- **Earth**
  - High-fidelity simulators and chambers
  - Analog ground-based (field) testing
  - KC-135 flight tests at various gravity levels
  - Integrated systems tests of leading candidates to "down-select"
- **Near-Earth**
  - No apparent benefits considering the vast operational and unique environmental differences between LEO and planetary surfaces.
- **Lunar**
  - Surface EVA in greater numbers & durations for system validation
  - Validate EVA traverse mapping & route planning techniques
  - Lunar surface conditions similar, but not truly "Mars-like"
- **Mars Robotic**
  - Mars robotic missions are key to providing martian environmental data (dust composition, thermal, radiation, terrain, hazards)

# Test Relevancy Summary (Score Averages)

DRAFT

| | Ground Testing | | | LEO Near-Earth | | Lunar Surface | | | Mars Robotic | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laboratory | Physical Integrated Testing | Field Test | ISS | Near Earth | Robotic | Short Stay | Extended Stay | Small | Large |
| **Crew Health and Performance** | | | | | | | | | | |
| Radiation Protection | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Long-Duration Crew Performance | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Advanced Life Support | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| EVA & Surface Mobility | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Advanced Habitation | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| **Space Transportation** | | | | | | | | | | |
| Aeroassist / Entry / Descent / Landing | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Propulsion - Chemical | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Propulsion - Solar Electric | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Propulsion - Nuclear Electric | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Cryogenic Fluid Management | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Rocket Exhaust Cratering | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| **Advance Space Power** | | | | | | | | | | |
| Fuel Cells | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Surface Solar | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Surface Nuclear | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| **Miscellaneous / Systems Related** | | | | | | | | | | |
| Advanced Communications | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Advanced Operations - Dust Mitigation | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Advanced Operation - Automation | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Automated Rendezvous & Capture | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Integrated Testing | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Integrated Testing - Mars Ascent | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Integrated Vehicle Health Management | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| In-Situ Resource Utilization | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Structures & Materials | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Supportability | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |
| Thermal Control | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ | ☞ |

☞ Very Relevant ☞ Somewhat Relevant ☞ Not Very Relevant

# Lunar Campaigns as Preparation for Mars Exploration
## Common Themes

- **Lunar test beds can serve a vital role in advanced technology tests to demonstrate long-duration performance and reduce mission cost supporting expanded human exploration**
  - Terminal descent and hazard avoidance
  - In-situ resource utilization
  - Science campaigns and instruments, EVA and mobility systems, and operational planning
  - Dust mitigation techniques
  - Radiation protection
  - Advanced operations and automation
  - Power generation and propulsion system testing

- **Lunar campaigns expand mission and science surface operations experience and techniques**
  - Long-duration “dry-runs”
  - Advanced operational concepts
  - Human and machine collaboration: Machines serve as an extension of human explorers, together achieving more than either can do alone
  - Operational experience on full-scale systems collected and evaluated prior to system deployment on a Mars mission

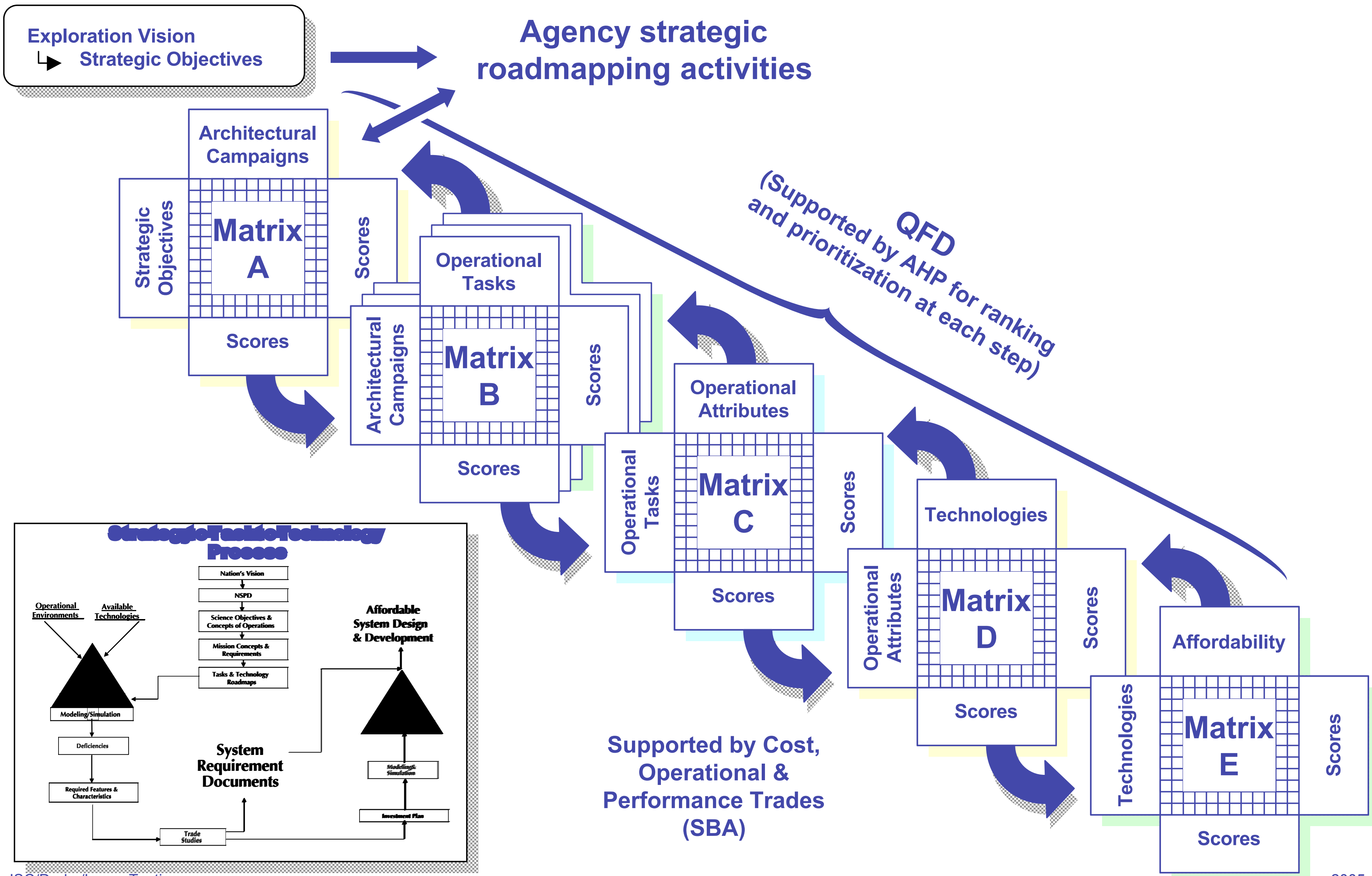
- **Breaking the bonds of dependence on Earth**
  - Life support system closure
  - Producing local propellants

- **Common investments in hardware systems for Moon, Mars and other space objectives**

# Next Steps

- **Apply Strategy-to-Task-to-Technology process to lunar test bed and lunar surface strategic planning assessment activities**
  - Rigorous, facilitated process involving requirements formulators, users (Operational Advisory Group), and technical experts
  - Provides traceability, linkage and prioritization of investments to strategies
  - Provides identification, assessment, and prioritization of user-defined future operational needs
  - Involves the use of Quality Functional Deployment (QFD) and Analytical Hierarchy Process (AHP) methodologies to provide insight

# Exploration Systems Quality Functional Deployment (QFD) Flowdown



# Strategy to Task to Technology (STT) Matrix-A

How's

What's

| | | | Architectural Campaigns (Roadmap Alternatives) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Strategic Objectives | | | Option-A: Evolution Emphasis | Option-B: Early Outpost | Option-C: Expedited Moon to Mars | Option-D: Commercial Emphasis | • | • | • | Scores |
| | Science | Understand the Composition of the Moon | | | | | | | | |
| | | Understand the Solar System | | | | | | | | |
| | | Search for Life on Other Planets | | | | | | | | |
| | | Astrobiology and Biological Science | | | | | | | | |
| | Preparation | Long-Duration Human Physiology | | | | | | | | |
| | | Demonstrate Operational Techniques | | | | | | | | |
| | | Perform Technology Test and Verification | | | | | | | | |
| | | Develop and Demonstrate Future Exploration Systems | | | | | | | | |
| | Security | Stimulate the US Economy | | | | | | | | |
| | | Enhance Strategic National Defense | | | | | | | | |
| | | Stimulate US Education (particularly in Science and Engineering) | | | | | | | | |
| | | Improve US Technological Competency | | | | | | | | |
| | | Provide Global Protection from Natural Threats | | | | | | | | |
| | Economic | Stimulate Commercial Transportation | | | | | | | | |
| | | Develop and Utilize Space Resources | | | | | | | | |
| | | Enhance the Commercial Tele-communication Market | | | | | | | | |
| | | Generate Space Power | | | | | | | | |
| | | Enable Entertainment / Advertisement / Tourism | | | | | | | | |
| | | Scores | | | | | | | | |

- **Each Level Describes a set of**
  - **What's** to be accomplished versus
  - **How's** to accomplish the what's

- **For example:**

  To what extent does the architectural campaign

  *Option B: Early Outpost*

  make a direct contribution to achievement of the strategic objective

  *Stimulate the US Economy*?

- **The process provides a good understanding of what the stakeholders need and want, what our strategies are, and how those strategies tie to the needs of the stakeholder**

# What Is a Lunar Test Campaign?

**Campaign – *"A connected series of determined operations or systematic efforts designed to bring about a particular result."***

**"… series of determined operations or systematic efforts…"**

– Progressive series of flight missions to the Moon

– Each mission builds off of the previous to establish new levels of confidence, prove additional technologies, develop the next level of operational experience, etc.

– Includes missions such as:

- Small robotic missions
- Short-stay human/robotic missions
- Long-stay human/robotic missions

**"… bring about a particular result."**

– Reduces future human Mars mission risk

- Proves technologies
- Provides better understanding of system performance and behavior
- Develops and refines operational concepts
- Lays the initial infrastructure for future missions